Particle Accelerators, 1990, Vol. 27, pp. 175–180
Reprints available directly from the publisher
Photocopying permitted by license only

BEAM-BEAM INTERACTION AND PACMAN EFFECTS IN THE SSC WITH MOMENTUM OSCILLATION

N.K. MAHALE AND S. OHNUMA
University of Houston, Houston, TX 77204-5504, U.S.A.

Abstract In order to find the combined effects of beam-beam interaction (head-on and long-range) and random nonlinear multipoles in dipole magnets, the transverse oscillations of "regular" as well as "pacman" particles are tracked for 256 synchrotron oscillation periods (corresponding to 135K revolutions) in the proposed SSC. Results obtained in this study do not show any obvious reduction of dynamic or linear apertures for pacman particles when compared with regular particles for $(\Delta p/p) = 0$. There are some indications of possible sudden or gradual increases in the oscillation amplitude, for pacman as well as regular particles, when the amplitude of momentum oscillation is as large as 3σ.

INTRODUCTION

The long-range interactions between two opposing beams are unavoidable when beams cross at a small but finite angle which is taken to be 70μr (vertical) in the model of the SSC in this study. Equally important may be the distortion in the vertical closed orbit caused by the vertical steering magnets, especially in the presence of nonlinear multipoles within superconducting bending magnets.

The pacman effect, named after the video game PAC-MAN, results from the abort gap in each train of bunches.[1] The gap is ∿3μs long corresponding to some 200 missing bunches. Unlike regular particles, pacman particles may encounter the abort gap in some interaction regions (IR) and experience different beam-beam interactions. Since it is not easy to have an independent orbit control for pacman particles, steering adjusted for regular particles will not eliminate the vertical orbit distortion of pacman particles completely. Coupled with the nonlinear multipole fields in the ring magnets, this distortion may be damaging to pacman particles and may even lead to loss of bunches in a chain-reaction manner.

There is an inherent difficulty in trying to estimate the pacman effect in the SSC with random nonlinear field errors in every dipole. Beam loss due to pacman effect will be a rather slow one even if the effect exists. It will be detectable in computer simulations only if the tracking covered 10^6 revolutions or more. When CRAY X-MP is used to run an existing code such as TEAPOT,[2] the required running time will be of the order of fifty hours and the reliability of results is by no means assured. The status of analytical investigation is even less encouraging. Presently available estimates of the long-term lifetime are arguably still in the realm of speculation for any practical (in contrast to idealized) situations of interest.[3] Since the tracking reported here covers only 135K revolutions, it cannot claim to establish anything definite on the long-term beam stability in the absolute term. The purpose of this study is simply to compare the behavior of pacman particles with that of regular particles to see if there are any indications of substantial differences. If none is detected, we conclude that the pacman effect as defined originally[1] will be absent in the SSC even though we cannot establish the stability of either regular or pacman particles.

SIMULATION MODEL AND TRACKING

Basic parameters of the SSC relevant to the present study are given in ref. 1. Other parameters and detailed explanations of the tracking can be found in the previous report of the same subject in which results for $(\Delta p/p)=0$ cases are presented.[4] The beam-beam interaction is assumed to be of the weak-strong type so that the closed orbit of the strong beam is kept fixed. A particle at a certain point in the four-dimensional transverse phase space is tracked and the quantity

$$W_z \equiv A_z^2 = (z/\sqrt{\beta_z})^2+(\alpha_z z/\sqrt{\beta_z} +\sqrt{\beta_z}\, z')^2 \;;\; z \equiv x-x_c \;\text{ or }\; y-y_c$$

is evaluated at one observation point in the ring.

Closed Orbit

It is easy to find the closed orbit (x_c, x'_c, y_c, y'_c) at the observation point in the ring for particles with $(\Delta p/p)=0$. For $(\Delta p/p)\neq 0$, the orbit can be defined unambiguously by considering an imaginary ring which is synchrotron oscillation period (=527 in this study) times larger.

Although the lattice of this imaginary ring consists of 527 "superperiods", the effective strengths of magnets in each superperiod are modulated in accordance with the momentum oscillation of the particle under consideration. Finding the true closed orbit is often a major undertaking since it can be found only by gradual change of the amplitude of momentum oscillation. Amplitudes of various closed orbits in units of the rms beam size σ_z are significantly different from zero for the vertical direction when the amplitude of momentum oscillation is three times the expected rms energy spread of the beam at 20 TeV (the only choice studied for non-zero $\Delta p/p$). It is 2.7 for regular particles and 7.0 for pacman particles.

RESULTS AND DISCUSSIONS

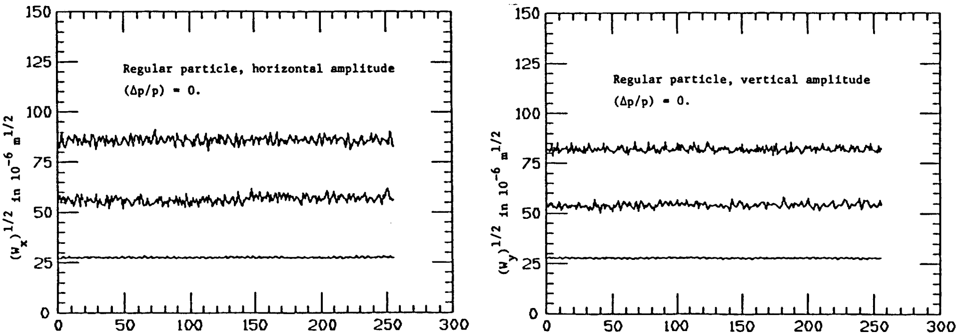
A. Particles with $(\Delta p/p) = 0$.

Main results for this case have been presented in the previous report.[4] The number of turns tracked there was 2,048 but this is now extended to almost 135,000. Figures 1 to 4 summarize the typical behaviors of both regular and pacman particles. Three cases in each figure represent amplitudes of 4σ, 8σ, and 12σ, simultaneously for two transverse directions. The only visible difference between regular and pacman particles is the enhanced degree of nonlinearity, often called "smear" in the absence of better names, in the horizontal direction for pacman particles when the amplitude is 12σ in both directions. Conclusions in ref. 4 are, for $(\Delta p/p) = 0$,

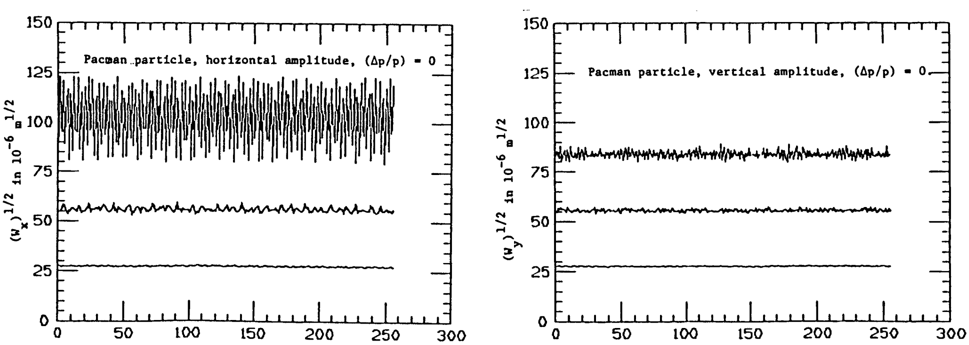
(1) There is no indication of any reduction in the dynamic or linear apertures for pacman particles when the oscillation amplitude is less than $\sim 10\sigma$.

(2) Smears often exhibit a strong dependence on tunes, casting some doubts on the wisdom of defining the linear aperture from the smear alone.

(3) At least up to the amplitude of 10σ, smears do not differ substantially for different choices of the seed number which generates a particular distribution of multipole fields (but with the same rms values).



FIGURES 1 & 2 Horizontal and vertical amplitudes of regular particles vs number of synchrotron oscillation. $(\Delta p/p)=0$

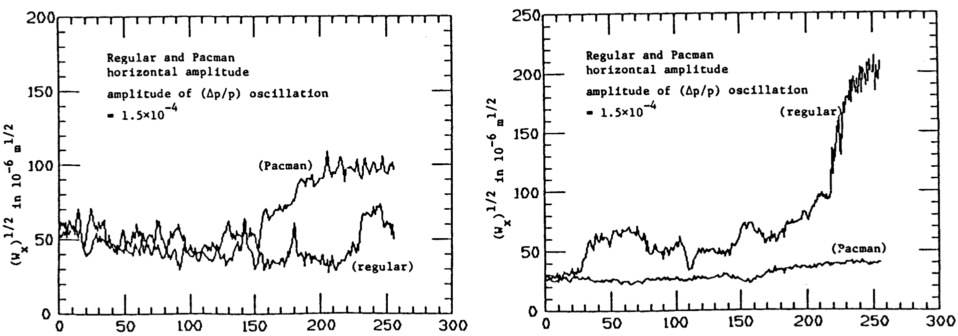


FIGURES 3 & 4 Same as FIGS. 1 & 2, pacman particles.

B. Particles with $(\Delta p/p) \neq 0$: effects of momentum oscillation

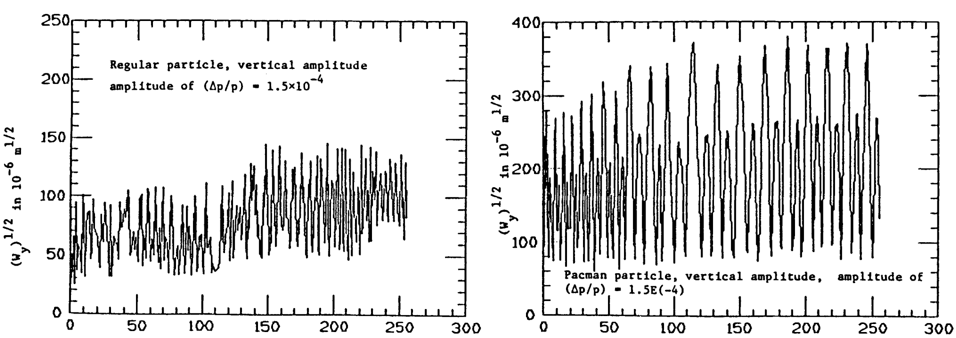
Two main effects of momentum oscillation have been examined with the amplitude of momentum oscillation = 1.5×10^{-4}: (1) tune modulations generated by the chromaticity $(\Delta\nu)/(\Delta p/p)=5$ in both directions and (2) modulation of the vertical steering angles at both ends of the interaction regions. At present, the required computing time is prohibitively large; tracking one particle for 256 synchrotron oscillations (≃135,000 turns) takes more than three hours on NEC SX-2 and more than five hours on CRAY X-MP. It should be possible to optimize the tracking code so that the running time does not increase proportionately with the number of particles but an order of magnitude increase in the turn number may necessitate an entirely new computer built specifically for the tracking purpose.

For the vertical direction, the change in linear parameters βy and α_y is considerable, especially for pacman particles. Coupled with the vertical closed orbit modulation of 7σ, the vertical amplitude $\sqrt{W_y}$ tends to fluctuate widely as a function of turn number. If the fluctuation is interpreted as "smear", there is a definite reduction in the linear amplitude for pacman particles (and maybe even for regular particles) when $(\Delta p/p)\neq 0$. However, more alarming is the sudden increase in the horizontal amplitude $\sqrt{W_x}$ as can be seen in Fig. 5 for pacman particles and in Fig. 6 for regular particles. Note that such an increase



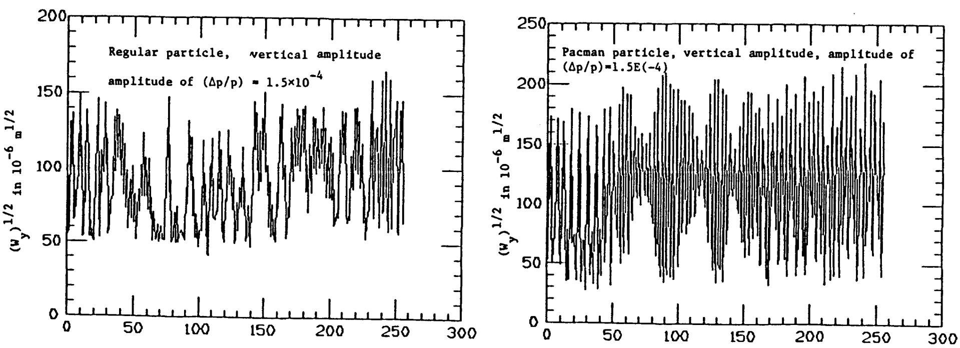
FIGURES 5 & 6 Horizontal amplitude, regular and pacman particles, vs number of synchrotron oscillations.

cannot be predicted from the initial amplitude alone and that regular particles are as susceptible to it as pacman particles. Equally alarming is the gradual increase in the average vertical amplitude as shown in Fig. 7 for regular and in Fig. 8 for pacman particles. Since the



FIGURES 7 & 8 Vertical amplitude, regular and pacman particles, vs number of synchrotron oscillations.

initial amplitude happens to be rather large, $\sim 8\sigma$ in Fig. 7 and $\sim 12\sigma$ in Fig. 8, it is perhaps necessary to study the behavior when the initial amplitude is not so large. The complex nature of the vertical motion when $(\Delta p/p)\neq 0$ is further illustrated in Figs. 9 and 10. Although the fluctuation of the amplitude is considerable, there seems to be little increase in the average amplitude, at least up to 135K revolutions.



FIGURES 9 & 10 Vertical amplitude, regular and pacman particles, vs number of synchrotron oscillations.

The study of the effect of momentum oscillation is still in the preliminary stage. We intend to study many more cases with varying parameters in order to establish the existence (or nonexistence) of the alarming beam behaviors detected so far.

ACKNOWLEDGMENT

We are grateful to Glenn Goderre for his contribution to this work in the early stage. Alex Chao was generous in releasing many hours of his CRAY time for us. The work has been supported by the US Department of Energy under grant No. DE-FG05-87ER40374.

REFERENCES

1. Conceptual Design of the Superconducting Super Collider, SSC-SR-2020, March 1986.
2. L. Schachinger and R. Talman, SSC-52 (1985).
3. S. Chattopadhyay, Proceedings of the Second Advanced ICFA Beam Dynamics Workshop, April 1988, Lugano, Switzerland.
4. G.P. Goderre, N.K. Mahale, and S. Ohnuma, to be published in the Proceedings of the Third Advanced ICFA Beam Dynamics Workshop, 29 May - 3 June, 1989, Novosibirsk, USSR.